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THE EVALUATION OF EXPERIMENTAL FABRICS AS ALTERNATIVES FOR STANDARD WOOL FABRICS

Herman Bogaty, et al

Harris Research Laboratories
Washington, D. C.

December 1951

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HARRIS RESEARCH LABORATORIES
1246 Taylor Street, N.W.
Washington 11, D.C.

Report No. 2

Quarter Ending December 25, 1951

THE EVALUATION OF EXPERIMENTAL FABRICS AS ALTERNATES FOR STANDARD WOOL FABRICS

Contract No. DA-44-109-qm-564

Project No. 93-10-014, Development of Alternate Fabrics to Conserve Wool.

Herman Bogaty and Norman R. S. Hollies

SUMMARY

1. The thickness-pressure relationships for a group of 21 serge constructions and 5 coverts have been determined in the pressure range 0.002 to 0.1 lb/in^2 both in the air dry and in the moist condition. The all-wool fabrics tend to be thicker than the blends, although napping of the blended fabrics is useful in increasing their thickness. The Orlon, Dacron and Dynel blends (30% synthetic) are similar in compressional resilience to the corresponding all-wool serge, while the all-cotton and all-nylon serges are lower in compressional resilience when the measurements are made dry. The resilience of the all nylon serge in the wet state, however, is greater than that for the other materials. The use of viscose in blending with wool tends to give a fabric of lower resilience and higher compressibility, especially when wet.

It is emphasized that methods of manufacture as well as fiber content influence compressional properties, since a group of all-wool serges exhibited considerabl differences among themselves.

2. A general equation, $t = a + \frac{b}{p+c}$, in which $\underline{t}$ = thickness, $\underline{p}$ = pressure and $\underline{a}$, $\underline{b}$ and $\underline{c}$ are constants is shown to describe the thickness-pressure relationships for a variety of materials over a wide range in pressures. The constants are of potential utility in characterizing fabrics.

3. Longitudinal wicking tests have been made on a series of blended fabrics and on a group of all wool fabrics of varying constructions. In general, the introduction of a non-wool component was found to decrease the wicking times, the values for viscose and acetate blends being notably reduced as compared with the all-wool fabric. On the other hand, a group of all-wool serges made by different manufacturers exhibited a wide range in rates of wicking, so that fiber composition of itself is not the only factor in determining this property Napping was found to decrease the wicking time. The use of fine yarns and especially high yarn twist was found to increase the wicking rate, and fabrics with denser textures also wicked more rapidly. Preliminary results on a transverse wicking test are presented.

4. Methods are described for evaluating the surface contact of fabrics, involving 1) visual examination of a folded fabric edge and 2) the rate of cooling of a warm metal disc in contact with the cool fabric. The latter test has been analyzed to determine whether a specific numerical evaluation of surface character could be obtained. It is shown that an estimate of the number of surface fibers may be obtained if the thermal conductance of the

[redacted]

fiber substance is known.

5. The thermal resistance of a group of alternate serges and coverts has been measured at thicknesses corresponding to 0.002 and 1.0 lb/in^2. At low pressures all of the samples were identical in thermal resistance per unit thickness. At 1.0 lb/in^2, however, differences in thermal resistance could be noted. For the particular fabrics studied, the addition of viscose and of Chemstrand to the blend resulted in fabrics of relatively low specific thermal resistance. Napping was effective in raising the specific resistance of some blended serges. The all-cotton and all-nylon serges were lower in specific thermal resistance than any of the other fabrics studied.

LIMITED USE DOCUMENT

DETAILS

I. Thickness - Pressure Relationships

A. Introduction

It has been clearly established that the thickness of a fabric is of importance in its thermal resistance; the nature of the surface, the height of the surface hairs and the compressibility certainly play a part in tactile impressions of a fabric as well as in service behavior. It is for these reasons that much attention has been given to the thickness-pressure relationships of fabrics. While there are certain difficulties in this problem inherent in the nature of the thickness- pressure relationship and in the inability to specify clearly the boundaries of a cloth, it was considered desirable to study the compressional behavior of alternate fabrics in view of its role in our subject.

It is proposed in the next sections of this report to discuss the meaning of compression measurements in the general case, to report some data obtained with the Schiefer compressometer on an array of experimental blended fabrics (serges and coverts) and to suggest a simple thickness-pressure relationship descriptive of fabric behavior over a wide range of pressures.

B. General Considerations and Definitions

It is desirable at the outset to consider what takes place during the course of fabric compression. As the presser foot moves towards the fabric, pressure against the foot begins to develop as the first long surface fibers make contact. This "defines" the thickness at very low pressures. As the pressure increases there is a relatively large decrease in thickness as more fiber contacts are made with relatively small pressure increments. During this increase in pressure to slightly higher values,

buckling and bending of the fibers occurs. When the pressure is of the order of 0.1 - 1.0 lb/in^2 most of the surface hairs are flattened and the thickness changes that ensue with further increase in pressure are much smaller; these may be due to compression of yarns and bulk fabric and to flattening of fiber and yarn crimp. With a view to analyzing the compression behavior of a fabric in terms of its fiber composition and construction, it may be fruitful therefore to distinguish two broad pressure regions; 1) Below 0.1 lb/in^2, in which the surface fiber effects are pronounced and in which such factors as the number of surface fibers present, their diameter, height of the surface nap and the stiffness of the fibers enter, and 2) Above 0.5 - 1.0 lb/in^2 in which the bulk fabric and yarn construction play a more important role in resisting compression.

Consideration of the use condition indicates that information with respect to the low pressure region is of great interest. Thus a fabric weighing 12 oz/yd^2 exerts a "self-pressure" of only -.0006 lb/in^2; this is about one-third the minimum value obtainable with the Schiefer instrument and many times lower than the usual 1 lb/in^2 test condition. Of course, in garment assemblies and at pressure points e.g. elbows and knees, the pressures may increase to many times the low value. Nonetheless for a great many conditions of use and for evaluation of the tactual character of fabrics, studies of the low pressure region are indicated. It is not intended to gloss over the importance of obtaining data at higher pressures as well. Thus a man in a sleeping bag exerts an average pressure of the order of 1 lb/in^2 on the fabrics beneath him and when he is sitting or kneeling, the pressures exerted are considerably greater. At this time, however, much of the subsequent data will deal with thickness measurements made at pressures ranging between 0.002 lb/in^2 and 0.1 lb/in^2.

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Before proceeding to the data on selected alternate fabrics, it may be helpful to define some of the parameters which one can obtain from the thickness data and to indicate what effects might be expected as a consequence of varying the nature of the fabric surface. In Table 1 are sketched thickness pressure curves of two hypothetical fabrics, compressed over a relatively small range in pressure. For simplicity they are assumed to be equal in thickness at the lowest pressure, the curves are drawn as straight lines over this range and values of the compressibility may be obtained from the difference in thickness at the two pressures. Since the work of compression is determined by the areas under the curves projected on the t axis, it will be seen that the work of compression is also proportional to the difference in thickness at the two pressures. With regard to the two hypothetical fabrics, sample I would exhibit low values of compressibility and of work of compression; it would be firm and hard compared with the soft, compressible sample II.

Included in this table are some of the possible surface characteristics which might be associated with the compressional behavior of fabrics I and II in the low pressure range. Thus the firm sample I might be made from a high modulus fiber, of high denier. It would be closely sheared and pressed and might be made of long staple fiber in a high twist yarn so that there were few fiber ends projecting from the yarn; another possibility for producing a fabric of this character would be to make a dense cut pile fabric with uniform but not too great pile height. Fabric II on the other hand might be manufactured from low modulus fibers of small diameter and short staple in a low twist yarn; the fuzziness might be emphasized by brushing or napping.

C. Measurements of Fabrics

Thickness measurements at pressures ranging from 0.002 to 2.0 lb/in^2 were made using the Schiefer compressometer. To encompass this range with the same spring, two sizes of presser foot were employed; a 5-inch diameter foot to cover the range 0.002 to 0.1 lb/in^2 and a 1-inch foot covering the range 0.1 to 2.0 lb/in^2. As indicated previously, most of the discussion in this section of this report will deal with the lower range. In passing, however, it is noted that differences among fabrics are much smaller at the higher pressures. Tests were made on air dry fabrics which had been laundered and conditioned at 65% relative humidity at 70°F. Preliminary measurements were also made on wet fabrics containing 15 percent water based on the conditioned weight. This test condition was chosen rather arbitrarily to simulate a moist but not dripping wet condition which was readily obtainable and fairly stable for the duration of the testing period.

The results of dry and wet measurements of some blended serges and coverts are given in tables 2 and 3, respectively. Included are data on the compressional resilience (calculated as described by Schiefer), the total compression between p = 0.002 and p = 0.1 lb/in^2 and the thickness at the lowest pressure. In line with the discussion in section B, it should be recalled that the total compression (or difference in thickness between these pressure limits) is related to the compressibilit

The effect of blending 30 percent of a synthetic fiber with wool is seen in comparing the serges in group A, all of these being made by a single manufacturer. The all wool fabric, 745 and the blends containing Orlon and Dacron are similar in compressional resilience both dry and wet. The resilience of samples 746, 747, and 748 tends to be lower than the others in the group. The lower resilience of the viscose blends especially when wet is not unexpected in view of the known wet properties of the viscose fiber. It can also be seen that the thickness of the all wool serge 745 is greater than any of the other group A serges; the second thickest sample is the viscose blend, 746. It is of interest that both of these fabrics exhibit the greatest amount of shrinkage in laundering and it is probable that their thickness is a consequence of the felting behavior of these fabrics. The results for total compression of these two fabrics indicates that they are softer, fuzzier and more easily compressible than the other fabrics in the group.

The serges in group B illustrate the effect of napping, the last three members of the group being identical with the first three except that they are napped on one side; sample 745 is the appropriate all wool control for comparison. The three unnapped blended fabrics are thinner and less compressible than the all wool material although the compression resilience is comparable. Of the three, however, the blend containing 30 percent Vicara is softer in handle and the higher value of total compression (equivalent to greater compressibility) is in agreement with the subjective evaluation. Napping increases the thickness and compressibility so that the fabrics become more nearly like the wool control in these respects. The resilience values, however, especially dry are decreased by this operation. That the wet resilience of the ternary blends, whether napped or unnapped is as high as it is may be due to the presence of the nylon which as is shown later exhibits good wet resilience properties.

The samples in group C comprise 3 non-wool fabrics in a serge construction. The nylon serges exhibit lower values of compressional resilience in the dry state than the fabrics containing substantial amounts of wool and the resilience of the cotton serge is even lower. This is in agreement with other data from these laboratories comparing similar fabrics and is consistent with experience. The compressional resilience of the wet nylon serge is, however, as good or better than the dry and the former is larger than that for the wool blends.

A series of all wool serges, group D, fabricated by different mills was also included in these tables to illustrate that methods of manufacture and finishing could also effect the compressional behavior appreciably. The compressional resilience of the fabrics in group D and of 745 are similar but the thickness and total compression differ markedly. Samples A and 13, for example, are quite different in handle, the former being firm and "hard finished" even after laundering and the latter exhibiting a fuzzy, hairy surface; these two samples are used subsequently in this report to illustrate differences in surface character. The data for the fabrics in group D indicate that caution must be applied in ascribing differences in fabric behavior only to the type of fiber present. It is clear that methods of manufacture (the effect of napping in group B is also a case in point) may exert a profound influence on the fabric behavior irrespective of fiber composition, and this is especially true where products of different manufacturers are compared.

The samples of group E are of interest in that they provide a family of coverts of increasing viscose content. The dry measurements do not indicate any appreciable differences except that the thickness of the all wool control, sample 26, is the largest in the group. The wet resilience and compressibility as indicated by the total compression appear to correlate with the rayon content; as the amount of viscose in the blend increases the wet compressional resilience decreases and the compliance increases.

In drawing conclusions from the above data, it should be recognized that manufacturing experience with fabrics of the type studied here are based to a great extent on the use of wool. Furthermore time effects on compression have not yet been studied and these are probably quite important with respect to a property like resilience. With these reservations, differences between the present blended fabrics and the corresponding all wool controls may be summarized tentatively as follows:

1) The all wool constructions tend to produce thicker fabrics; this is presumably a consequence of the unique felting and frictional properties of the wool fiber. Napping, however, may be useful in increasing the thickness of the blends.

2) The compressional resilience as determined herein is similar for the Orlon, Dacron and Dynel blends and the all wool controls. The resilience of the all cotton serge is lower than that for the wool blends and the nylon serge lies intermediate in value when the measurements are made in the dry state. In the wet state, the resilience of the all nylon serge is greater than those of the other materials; the use of such hydrophobic fibers in ternary blends with lower proportions of wool may serve to increase the wet compressional resilience.

3) The use of viscose in blending with wool results in a fabric of lower compressional resilience and higher compressibility especially when wet.

4) Method of manufacture is quite important in the compressional behavior of fabrics and must be considered along with fiber composition in making comparisons.

D. General Thickness - Pressure Relationship

It would be desirable to express the thickness-pressure behavior of a fabric in algebraic form for a number of reasons if this could be done simply. First, the whole thickness-pressure curve could be described briefly by means of the equation constants and the thickness at any given pressure could be determined. Secondly, if the form of the equation were chosen appropriately, a strong possibility would exist for the constants to have a real physical meaning relating to the characterization of the cloth, the fibers composing its surface and to other particulars of its construction.

Some work in this direction has been done, especially for describing the compressibility of bulk fibers (e.g. Van Wyk, J. Textile Inst. 37, T285 (1946). For fabrics, exponential relationships (see for example Hoffman & Beste, Textile Research J. 21, 66 (1951) have been suggested.

In the course of this work, the possibility for expressing the relationship between thickness, t, and pressure, p, as a hyperbolic function was considered. Examination of a typical t, p, curve suggested the form:

(1) $$t = a + \frac{b}{p + c},$$

where a, b and c are constants. Calculation of the constants for a variety of test materials, including serge, covert, blanket, flannel, velvet and rubber, indicated that the value of b was a constant up to p values of approximately 0.1 lb/in^2 and that in the case of many fabrics, this value suddenly increased to a new constant value about twice as great at higher pressures; this will be discussed at a later point in this report. However, it will be noted that as p increases in equation (1), the value of the fraction $\frac{b}{p + c}$ approaches zero and t approaches the value a. Because of the form of this equation and the relative magnitude of the constants, therefore, it is possible to employ equation (1) to predict the thickness, t, with good precision at any pressure, p using the value of the constant, b, obtained from the low pressure region. Comparisons of the observed and calculated thickness for three widely different types of fabric - an all wool serge, an all cotton "serge", and a chlorinated wool blanket with a long brushed nap - are shown in Table 4. The agreement between the observed and calculated values of thickness is seen to be very good over the entire range despite the "inconstancy" of b and this indicates the usefulness of such an equation for descriptive purposes.

For purposes of record, the method of calculating the constants were as follows: a and c were determined from the values of t observed at p = 0.004, .04, .02 and 1.0 lb/in^2. The constant, a, was averaged for the loading and recovery cycle. The value of b was taken as the mean value calculated from the equation at thickness observed at each station below p = 0.1 lb/in^2. The results given in Table 4 and other similar calculations not here reported indicate that a function of the form of equation (1) may be used to describe the thickness-pressure relationship of a wide variety of materials.

Some thought has been given to the significance of the constants in equation (1). In figure 1 a graph of equation (1) has been drawn which illustrates, geometrically, the meaning of the constants. The constant, a, can be seen to be the value of t when p becomes very large; that is when the fraction $\frac{b}{p + c}$ becomes vanishingly small at higher pressures. With regard to a fabric therefore, a represents the thickness of the base fabric plus compressed fuzz, a kind of limiting thickness at high pressures. When $p = 0$, the thickness is given by $a + \frac{b}{c}$ and hence $\frac{b}{c}$ represents the total compression possible. If equation (1) is re-arranged algebraically in the form:

$$(2) \qquad (p + c)\ (t-a) = b,$$

a number of new interpretations are evident.

Equation (2) is in the same form as van der Waals' equation for the pressure-volume relation of gases. In brief, the van der Waals equation of state applies corrections to the pressure and volume of an ideal gas to account for the attractive forces between the molecules and for the volume actually occupied by the molecules, respectively. The analogy to the fabric case is quite interesting. The constant, a, is a correction to the thickness (or volume) of the fabric which corrects the thickness at any pressure for the space occupied by compressed yarns and fuzz. The constant, c, is a correction to the pressure, which accounts for the fact that the fabric does not become thicker without limit as the pressure decreases; this may be thought of as analogous to a type of force of attraction between the fibers and yarns which holds them together when there is no external pressure present.

In the case of a gas, the product of corrected pressure and volume is related to the energy of the gas. That the constant, $b = (p + c)(t - a)$, for the fabric is equivalent also to an energy or work can be seen in that it corresponds geometrically to an area under the t, p curve, shown shaded in figure 1.

The importance of the constants in some of the derived parameters useful for characterizing fabrics was considered. For example, the compressibility may be calculated from equation (1) as:

$$\frac{dt}{dp} = -b/(p + c)^2 \qquad (3)$$

and for very low pressures, this reduces to $-b/c^2$ and for larger pressures to $-b/p^2$.

It was noted above that the value of b for fabrics rises as the pressure increases above 0.1 lb/in^2 to about twice that at low pressures. While the significance of this is not clear as yet, it suggests that two distinct mechanisms operate during compression as has been suggested by Finch and by Hoffman and Beste. It seems reasonable that the view of compression set forth in section B is consistent with this result, and it may be that further analysis of the compression process may make possible a more specific interpretation of the constants. The increase in the value of b is furthermore reminiscent of the observations of Hoffman and Beste; these workers noted in their formulation for the thickness-pressure function, $p = f(t)^k$, that the exponent k, "showed the curious feature of increasing suddenly from a value of about 5/4 at low pressures to a value of about 3 at medium and high pressures". Hoffman et al also suggest that this change in constant reflects a change in the compression process from bending of superficial hairs to a real compression of bulk fabric.

In order to give some idea as to the magnitude of the constants and to determine whether even empirically, the constants would reflect obvious differences among materials which were different tactually, visually and construction-wise, measurements of thickness over a pressure range p = 0.002 to 2.0 lb/in^2 were made on a number of materials and the constants calculated to fit equation (1). These are summarized in Table 5; in this table are included the values calculated for a, c for loading and recovery cycle (subscript l and r respectively) and the value of b for the loading cycle calculated from the data obtained at high pressure (above 0.1 lb/in^2) and at lower pressures.

Examination of the data indicates that the constants indeed reflect differences among the fabrics. Thus, in the first group of serges, the hairy wool serge, sample 13, exhibits a higher value of b than do the firmer serges A and 28. The hard cotton serge, 28, exhibits a lower value of b than the sample A. The softer, fuzzier covert, sample 25 has an even higher value of b. Sample CF, a thin cotton flannel has a soft, compressible surface compared with the firm serge, sample A, and this is reflected in the value of b. When a thick easily compressed fabric like the wool blanket, HB, is considered, the magnitude of b is seen to be many fold greater. In comparing the sample of sponge rubber with the wool blanket, the constant b for the former is considerably larger and this material acts like a very thick, soft fabric. The thinner, incompressible rubber sheet on the other hand exhibits a very low value of b. It is noteworthy that the constants obtained for the rubber materials are virtually the same for the loading and recovery cycles, indicating the completeness of recovery from compression. The case of the rayon velvet is of some interest. It might be supposed that a

pile fabric of this type would give constants similar to the hairy or fuzzy fabrics, whereas in fact the values of b are more nearly similar to the smoother firmer fabrics. Actually the tactual sensation given by this cloth corresponds more closely to the firm, hard fabrics so that the constants appear to represent this fact truthfully. It is quite likely that a pile fabric with many straight projecting surface fibers, presents a uniform, smooth incompressible surface to the presser foot or the fingers such that it is similar in behavior to a truly smooth, hard surface. This would be more probably so if the pile were not too long (and hence not easily collapsed), and if the pile were dense and uniform in height; this is the case for sample RV.

Tests were also made using two families of fabrics differing in certain fiber characteristics: diameter and crimp. A series of blended jerseys were available, containing 60% wool and 40% Vicara, in which the denier of the Vicara was varied between 3 and 7, as well as a pair of lightweight dress fabrics containing 67% viscose and 33% wool in which crimped fiber was used in one case and not in the other. The comparable fabrics were otherwise manufactured to be as similar as possible. Examination of the calculated constants reveals considerable differences, especially in b, and particularly for the jerseys. In both cases, subjective judgments of handle correspond to the magnitude of the constant b, the fabrics increasing in "loftiness" and hairiness with increasing b.

The data presented in tables 2 and 3, and the discussion above suggest that characterization of a fabric by means of the constants in an equation of the type of equation (1) may indeed be feasible. It is tempting to speculate that the constant b (at low pressures) and perhaps c may be interpreted in terms of the height of the surface fibers, and their number, stiffness and diameter. This can be pursued by examination of fabrics appropriately designed with these variables in mind, by the development of improved techniques for the measurement of low pressure compressibility and by comparison with other means for evaluating the nature of the fabric surface.

II. Wicking

A. Effect of Construction Factors

While the role of the wicking behavior of fabrics in comfort aspects of clothing has not been established, it is clear that fiber blending and fabric construction affect the wicking characteristics significantly. It is expected that experiments under way at the Climatic Research Laboratories will provide guides to our understanding of this problem with respect to use conditions.

There is, however, little quantitative information as to how blending or construction variables influence the wicking behavior. A number of fabrics were available from other work in these laboratories in which construction factors were varied. These samples were all wool and the construction variables included texture, yarn number, weave, twist and ply. The opportunity was taken to test these fabrics using the simple longitudinal wicking test discussed in the previous quarterly report in order to obtain some idea as to which construction factors

influenced the wicking behavior. The time required to wick to a height of 1 inch is given in table 6, together with the construction variable in question. It is to be noted that these fabrics were all unfinished (in the loom state) and washed gently by hand to remove spinning oil. The samples are grouped in the table so that the fabrics in a given group may be considered as otherwise identical except for the construction variations noted.

The texture of the fabric can be seen to influence the wicking time appreciably. For these fabrics, those with denser weaving appear to wick more rapidly. It is interesting to observe that this effect is noticeable in the warp direction as well even though texture changes were accomplished by varying the filling thread count.

The next pairs of fabrics listed in the table were identical except for the yarn size. Pair b and l had a thread count of 31 x 16 and the use of the larger yarns effected only a minor increase in wicking time. The second pair, a and k, had a thread count of 31 x 22, and in this group the fabric woven with the coarser yarn exhibited slower wicking also.

The final pair in table 6 was examined by testing of yarns removed from the cloth; this procedure may be of interest for the study of fabrics in general since it isolates the yarn structure physically from the finished cloth. The twist in the singles yarn exerts a profound effect on the rate of wicking in the yarn. The transport of water through the high twist yarn is many fold more rapid than through the low twist yarn.

The results obtained for the effect of yarn number and of yarn twist are in agreement with the data of Baxter and Cassie (J. Text. Inst. 36, T67 (1945)); these workers indicate that the wetting time decreases as the yarn is finer, and as the twist is higher.

The texture effect may be visualized by assuming that water is transported not only in the capillary space between fibers but between yarns as well. Hence with open structures not only is the yarn spacing greater but there are fewer total paths available to the liquid. It is noteworthy that tests of wicking time with yarns taken from fabrics a, b and c gave identical results.

It is hoped by further testing of additional comparable fabrics and of yarns that a quantitative basis for separating the effects of yarn and fabric construction, fiber composition and finishing can be obtained.

B. Wicking of Alternate Fabrics.

As part of the program of the evaluation of alternate fabrics, the series of serges and coverts discussed in section I of this report (tables 2 and 3), were tested by the longitudinal wicking procedure. The results are given in table 7, comparable fabrics being grouped together for convenience.

In group A, the all wool serge was not wet in 4 hours, whereas all of the blends wicked in 15 minutes or less. In this group of blends, the Dacron blends, 742 and 744, exhibit slowest wicking whereas those blends containing viscose, 746 and 747 wick most rapidly. The effect of viscose in producing a rapidly wicking fabric is also seen in group E in which progressive additions of viscose in the blend reduce the wicking to a very low level.

In group B, the Dynel blend and the ternary blend containing Vicara and nylon are seen to show relatively large wicking times for blended fabrics while the serge containing acetate wicks quite rapidly. The napping process can be seen to increase the wicking time considerably by comparing the first three members in group B with the corresponding napped fabrics, the last three samples in this group.

Group D is a series of all wool serges made by different manufacturers included as before to illustrate that finish and/or construction may affect a fabric property as much as the use of another fiber type in minor proportion. Samples A, 13 and 745 are wetted by the water during test with great difficulty; samples K and particularly H wet out and wick with great ease. It is not possible as yet to assign the reason for these results. It should be observed in passing, however, that all of these measurements were made using samples laundered three times with Igepon T as detergent in order to smooth out any gross effect due to residual oil, wetting agent and the like.

C. Transverse Wicking

The normal use of fabrics in apparel leads to moisture transfer normal to the cloth surface. While the methods for evaluating longitudinal wicking of the type discussed in previous sections of this report are instrumentally simple, it is possible that they may be misleading in minimizing the role of the fabric surface in impeding or accelerating wetting.

An attempt was made to estimate the rate at which water is transported transversely through a fabric using as the detecting mechanism, the rate of change of electrical capacity. It was hoped that in this way differences in the wicking rate as between surface and bulk fabric might be investigated. It was found, however, that the equipment available was insufficiently sensitive for this purpose. Nonetheless, it was possible to determine a total transverse wetting time which corresponded to penetration through the fabric and it was thought desirable to present comparative data for transverse and longitudinal wicking at this time.

A circuit involving the tuning of two high frequency oscillators was used to measure capacity. The cell consisted of a guarded electrode plate on which the fabric specimen was placed; the area of the inner electrode was 0.80 cm^2. A small flat bottomed brass cup was placed on the specimen; the area of the bottom of the cup was 0.50 cm^2 and through it was drilled a hole 0.50 cm in diameter. At the beginning of a run, 0.6 ml of water was added to the cup and a #18 platinum wire lowered into the liquid to complete the electrical circuit. The time required for the cell capacity (14.00 micromicrofarads) to increase 100 percent was chosen as the transverse wetting time. This corresponded to penetration of water to within 0.03 mm of the bottom electrode.

The results for wicking tests on several blended shirtings after laundering are given in table 8. Individual values for the transverse wicking did not vary by more than 9 percent for any one fabric and in general agreed within 5 percent. Included for comparison are data for longitudinal wicking on the same fabrics, the time required to rise one inch up the fabric.

Now, it is possible to assume three phases in the transverse wicking process. First the water must wet the fiber, secondly the liquid must penetrate the rather diffuse surface fiber region and finally the water must penetrate the bulk fabric. The wicking results for sample 6 are explained by the fact that wetting of the fiber did not occur at all in the times noted.

It is probable that in the longitudinal wicking test the rate of liquid penetration through the surface fibers is not as important as in transverse wicking, once wetting occurs, since fabric edges are freely exposed to the liquid in the former. Since the longitudinal wicking times for samples 1, 4 and 12 are similar it may be supposed that these fabrics wet similarly and are alike with respect to rate of wicking through bulk fabric. The transverse wicking times on the other hand are quite different, sample 12 for example being much slower in this regard. This result suggests that the rate of liquid transfer through the surface is slower in sample 12, although perhaps much of the difference may be accounted for by the greater thickness and fuzziness of this fabric.

Sample 2, however, which is similar in thickness to a number of other samples appears to wet rapidly and be rapidly penetrated by the water.

It is felt that transverse wicking, especially under low load conditions, is a desirable means for evaluating fabrics since this corresponds to use behavior. It would also be of interest to attempt a separation of the components of the wicking time:wetting, penetration of the surface and wicking through bulk fabric. It is intended to pursue this line of investigation further.

One further fact may be noted from the data in table 8. The transverse wicking result depends in no obvious way on the fiber compositi as such. It seems likely that construction and finishing effects especia with blends rich in wool are of greater significance to this property.

III. The Surface Contact of Fabrics

A. Visual Evaluation

In the previous quarterly report, some attention was given to the determination of the surface contact of the fabrics. The importance of the type and number of fiber contacts between a fabric surface and its environment is easily recognized in terms of the transfer of heat and moisture, and of certain other psycho-physical characteristics such as handle. Most of the instrumental techniques previously described have suffered to some extent in requiring the fabric to be tested under some pressure and frequently in being less sensitive than subjective judgments.

Visual examination of the fabric surface has been found to be a very useful means of judging the relative hairiness of fabrics. Since some use has been made of this technique in enabling decisions to be reached with respect to the equivalence of the surface character of fabrics, the procedure employed is recorded here. The fabric to be examined is folded diagonally to the principle directions of the cloth and placed between two glass plates. 3-1/4 x 4 in. projection slide plates have been found suitable. In the case of twills, the fold has generally been made perpendicular to the twill line. Care is taken to avoid disturbance of the fibers at the folded edge. The assembly is then placed in a photographic enlarger and the image focused on a film at a distance sufficient to give enlargement of approximately 7 X.

A photograph is made on the film and then enlarged when printing to give an overall magnification of 14 X. Some photographs taken in this way are attached to this report. The fabrics include sample 13 (hairy wool serge), sample A (smooth wool serge), sample 28 (cotton serge), sample N1 (worsted spun, 3 in. staple, nylon serge) and sample N2 (cotton spun, 1-1/2 inch staple, nylon serge). The contrast in hairiness between sample A and 13, both all wool serges is quite marked. The cotton serge is also moderately hairy. The difference in fuzziness in the 2 nylon serges illustrating the effect of staple length and method of spinning is of considerable interest, in that the short staple cotton spun sample N2, is visibly more "wool-like" with respect to surface character.

B. Thermal Conductivity Method

The last report described a method for evaluation of surface contact which involved measurement of the cooling of a "hot penny" at 37°C. in contact with the fabric at room temperature. Some minor modifications of the apparatus and technique have been made in order to improve reproducibility and to facilitate analyses of the data. While further improvements are being contemplated, measurements of a number of blended serges were made. The data summarized in table 9 give the time, $t_{1/2}$, for the metal surface to reach half way to the equilibrium temperature (a decrease of 7.5°C). It is believed that differences of 3 seconds in $t_{1/2}$ are significant in this test. It should be noted that a low value of $t_{1/2}$ indicates a smooth fabric making good contact with the heated metal surface and that this corresponds to a relatively large rate of cooling.

Comparison of the all wool serges A and 13 indicates that sample 13 is hairy and sample A smooth and this is in good agreement with the visual (see photographs) and tactile impressions of these two fabrics. In fact it was found that with samples similar in type, e.g. those containing substantial amounts of wool, samples which differed in $t_{1/2}$ by as little as 3 seconds could with a little practice be readily distinguished with respect to handle.

Within the "700" (NRC) series of serges, sample 746 containing viscose was most nearly similar to 745, the all wool control. The others in the group were slightly smoother and were much alike with the exception of sample 744; this latter sample containing 30% Dacron was appreciably smoother by this criterion and by the subjective judgment of handle than the other NRC fabrics. It is interesting that this fabric showed the least shrinkage in laundering of any of this group (made by a single manufacturer) although all of the shrinkage values were quite low. It is also worthy of notice that of these blended fabrics, sample 746, containing viscose exhibits shrinkage in laundering comparable with the all wool control, the other blends felting less; this result is consistent with other work in these laboratories which indicates that the addition of many synthetics, especially of the hydrophobic types, will decrease the feltability of a blend, whereas viscose-wool blends may exhibit an equal or even greater tendency to felt in laundering when compared with an all wool fabric. It is quite probable in any event that felting whether during manufacture or laundering does exert a significant effect on the fuzziness of the fabric surface.

The effect of napping can be seen in the next group of fabrics. Samples 20, 21 and 19 correspond to samples 54047, 54048 and 54049, respectively, the former group being lightly napped during manufacture. The napping process is seen to produce an obvious decrease in the extent of surface contact, as would be expected.

The all cotton and all nylon serges are seen to be very smooth in terms of this test. This result is in agreement with subjective judgments of handle but seems to be inconsistent with the visual impression obtained from the attached photographs. This can be explained in the light of the fact that finer fibers compose the surface of samples 28, N1 and N2 compared with the wool blended serges. Thus, under the test conditions, the fabrics being loaded under a pressure of 0.1 lb/in^2, the surface fuzz is compressed and the fabrics behave as if they were smoother. It should be emphasized that in addition to the number and height of the surface fibers, this test is necessarily affected by the specific thermal conductance of the fibers. The available data from the literature indicates that cotton has a considerably greater conductance than wool and on this account fabrics made from cotton might be expected to exhibit more rapid cooling in this kind of test.

In summary, this simple technique is seen to give a useful quantitative measure for estimating the surface hairiness of fabrics which in general appears to correlate with visual and tactile impressions. In view of its utility, an effort was made to analyze this method further, to determine whether the results could be interpreted to give specific estimates of the number of fibers on the surface or of the surface fiber height as other useful data descriptive of the fabric surface.

C. The Estimation of Number of Surface Fibers

In order to obtain a more specific estimate of the nature of the surface, a theoretical analysis was made of the flow of heat in a hot penny experiment. The assumptions made and the detailed derivation of equations will be given in the next report. It can be shown, however, that the following relationship should hold:

$$\frac{nk}{l} = C\,(m - m_o - m_a), \qquad (4)$$

in which n = number of fiber contacts per unit area;

k = specific conductance of the fiber in cal/sec/deg/cm length;

l = mean fiber length assumed to be equal to the height of the fl

c = an apparatus constant = $2.303\,\frac{Mc}{A}$,

where the hot penny has a mass $\underline{M}$, surface area $\underline{A}$ and specific heat $\underline{c}$;

m = slope of the linear curve relating log temperature change to time in "hot penny" experiment;

m_o = correction used to account for losses to the insulation surrounding the penny; and

$m_a = C\bar{a}k_a$, = correction used to account for the losses to the air intermingled with the surface fibers, where $\bar{a}$ is the effective fractional area of the surface of the test material which is air and k_a is the specific conductance of air.

This equation relates certain fabric properties - number of surface fibers and their length and conductivity - to data obtainable from experiments using the hot penny apparatus. The value for the correction term m_o, was obtained by making hot penny runs with a wide variety of substances of known conductance: air, paraffin, glass, Lucite and polystyrene. Plotting the logarithm of the temperature change against time yielded linear curves from which slope, $\underline{m}$, could be obtained.

A graph in which this observed value of m is plotted against the values for the specific conductance of these materials (obtained from the literature) is shown in figure 2. Extrapolation of this curve to zero conductivity gives an estimate of the value of m_o = 0.00215 $sec.^{-1}$ The linearity of the relationship in figure 2, provides a test of the validity of the theory concerning losses to the insulation for materials ranging 300 fold in conductivity.

To verify this correction in another way, 3 synthetic "pile" fabrics were prepared by cementing a number of layers of open mesh polyethylene monofil fabrics together. By raveling the fabric pieces to a greater or smaller degree prior to lamination, assembiles with longer or shorter pile heights (l) were obtained and by using fabrics of greater or lower thread count, fabrics of greater pile density (n) were obtained. Tests of these simulated pile fabrics of varying but known n/l were made with the hot penny apparatus. Plotting $m - m_a$ as a function of n/l and extrapolating to zero n/l yielded a value of m_o = 0.00208, in excellent agreement with that obtained from figure 2, so that in the subsequent work an average value of m_o = .00212 was used.

In the case of these simulated pile fabrics, the true value of $\bar{a}$ and of m_a could be obtained from measurements of the monofil diameter and the pile density. The possibility of using an estimated value of $\bar{a}$ = 0.9 in the general fabric case was tested for these three polyethylene fabrics by performing the test and calculating the values of n/l from equation (4). The comparison between calculated and observed values of n/l is given in the upper portion of table 10 and the agreement is seen to be quite satisfactory. This is a good test of the general approach and also demonstrates that the assumption that the fabric surface is effectively 90 percent air may be adequate for most purposes in the case of real fabrics.

Tests were also conducted with 3 serges - sample 13, a hairy wool serge, sample 4, a smooth wool serge and sample 28, a cotton serge. These fabrics were judged to be quite different in appearance (see attached photographs) with respect to the fuzz height, l, and with respect to the degree of surface contact.

The hot penny tests were made, the slope m of the log temperature vs. time curves obtained and $\frac{nk}{l}$ was calculated from equation(4). Values of k from the literature for cotton and for wool (1×10^{-3} and 5×10^{-4} cgs units respectively) were available and hence n/l could be estimated, the results being shown in the lower part of table 10.

Now an estimate of l, the fuzz height, is possible from the compressibility measurements. If the fabric thickness at 0.1 lb/in^2, the pressure in the thermal test, is assumed to give the height of the surface fibers plus bulk fabric and the thickness of the fabric at 2.0 lb/in^2 is a measure of the thickness of the bulk fabric, then one-half the difference between these thicknesses gives an estimate of the height of the fuzz (l) on one side of the fabric. Accordingly from the value of n/l and the estimated length of the surface hairs from compressional data, a numerical estimate of the number of contacts may be made which appears to be correct within an order of magnitude at least. The results given in the lower portion of table 10 suggest that the number of contacts for sample 4 and 13 may be similar but that they differ chiefly in the length of the surface fibers. Sample 28 and 4 are similar from the point of view of height of the fuzz (under conditions of the test, 0.1 lb/in^2 pressure) but the cotton fabric has a greater density of surface fibers.

It is possible that the parameter n/l of itself may be a useful criterion for characterizing fabrics. Thus in the group of 3 serges, the calculated n/l values rate the fabrics in proper order with regard to the "hardness" of finish, a large n/l being associated with a hard, smooth handle.

In summary it may be stated that analysis of data from experiments with the hot penny apparatus yields useful estimates of nk/l. If values of k, the conductivity of the fiber are known or can be measured and if l, the height of the fuzz can be estimated from thickness data, then n, the number of surface fibers may be calculated.

For future work, additional verification of the theory can be attempted using velvets or carpets of known pile height and density. Since data on various fibers differing in thermal conductivity will be of interest, it is intended to consider ways of determining k on single fibers. Finally it is intended to evaluate a number of the blended fabrics with respect to surface contact by means of the thermal conductivity technique as compared with results from other methods of estimating surface contact, e.g. visual means or the electrical conductivity technique discussed in the previous report.

IV. Thermal Resistance of Alternate Fabrics

In report No. 1, data were presented for the thermal properties of some blended fabrics using a modified Cenco-Fitch conductivity apparatus. This work has now been extended to cover a series of blended serges and coverts, measurements being made on air dry laundered fabrics at thicknesses corresponding to 0.002 lb/in^2 and to 1.0 lb/in^2. The results are given in table 11.

At the low pressure, the thermal properties are seen to be governed largely by the thickness of the fabric and associated air layers. The specific thermal resistance for all the fabrics irrespective of fiber composition or construction is 2.00 ± 0.15 so that consistent with the results reported previously the various fabrics are not distinguishable with respect to thermal behavior at low pressures.

At a pressure of 1 lb/in^2 on the other hand, the thermal conductance of the fiber substance itself makes a bigger contribution to the thermal resistance of the fabric, since the bulk density is greater than at a pressure of 0.002 lb/in^2. That is, the volume fraction of the fabric which is fiber is greater and the overall conductance of the fabric (fiber + air) is composed in larger part of the larger fiber conductance.

The data in table 11 indicates that the specific resistance at 1.0 lb/in^2 is generally lower than at 0.002 lb/in^2. The low specific resistance of the all nylon serges, samples N1 and N2 and of the all cotton serge, 28, may be associated with a very smooth surface, as suggested by the results in section III of this report. The high specific conductance of the cotton fibers themselves may account for the thermal behavior of sample 28; this is suggested by the data in the literature (Baxter, Proc. Phys. Soc., London 58, 105 (1946) which indicates that the cotton fiber may conduct heat several times more rapidly than wool.

Of the serges in group A, the fabrics containing viscose and Chemstrand, 746, 747 and 748 tend to exhibit lower specific thermal resistance than the other blends. The wool control, 745, exhibits the highest resistance and the Dacron and Orlon blends are high with respect to the thermal resistance; of the group of Orlon or Dacron blends, sample 744 shows the lowest thermal resistance, possibly due to the relative smoothness of this fabric as noted previously.

The data for group B indicates that napping produces a surface which traps air more effectively even at higher pressures, the napped fabrics 20, 21, and 19 showing better thermal properties per unit thickness than the corresponding unnapped samples 54047, 54048 and 54049.

The results for group D and sample 745, various all wool serges, are consistent with the view that smoothness or fuzziness of surface influences the thermal behavior at 1.0 lb/in^2. The fuzzier fabrics tend to exhibit higher values of specific resistance and conversely for the smoother, harder finished cloth.

The family of coverts, group E, includes fabrics of increasing viscose content. While there is not complete correspondence between fiber content and specific thermal resistance, the samples containing larger amounts of rayon are less resistant to the transfer of heat. It is possible that this result is a consequence of the fiber conductivity

These results indicate that for many conditions of use in which the fabric is subjected to little compression, the thermal resistance is given by the thickness and the effective fabric component is air. Under conditions of use involving higher pressures not only are the compressibility and surface character of the cloth involved but the fiber conductance may be of some importance. Much of the data in the literature on this latter point is conflicting and there is virtually no information on the newer synthetics. In view of our interest in this subject with respect to thermal behavior and to the surface contact work discussed previously, it may be worthwhile to measure single fiber thermal properties; this is being considered.

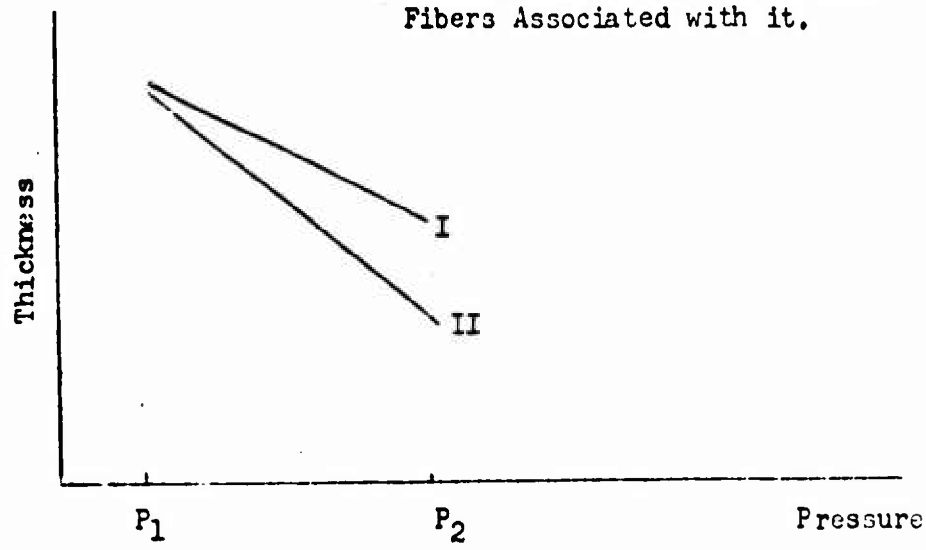
In addition plans are in progress to measure the thermal behavior under moist conditions since it is possible that differences between blends will be more pronounced when this procedure is used. Construction of an apparatus with which thermal measurements are possible under "sweating man" conditions is underway. It is hoped that preliminary details will be available for the next quarterly report.

V. Erratum

It has been found that the densities in Table 4, Report No. 1, were incorrectly calculated. The density of the fabrics reported was too high by a factor of 0.696. Multiplication of the values reported by this constant factor will give the correct value for density. The conclusions drawn from these results remain valid, however, since the relative order of the density was correct in the table.

noted on table.

Table 1, Report 2. The Compressional Behavior of 2 Hypothetical Fabrics and the Characteristics of the Surface Fibers Associated with it.



Property	Magnitude of Property: Fabric I	Magnitude of Property: Fabric II
Fabric Properties		
Compressibility	Low	High
Work of Compression	Low	High
Surface Fiber Properties		
Modulus	High	Low
Denier	High	Low
Fuzz height	Short	Long
Number of Surface Fibers	Few or many of uniform short length	Many
General Fabric Character	Firm, Hard, Springy, Bristly	Soft, Dead, Compressible

Table 2, Report 2. Compression Measurements of Air Dry Blended Fabrics in the Pressure Range 0.002 to 0.1 lb/in^2.

Sample No.	Fiber Content Wool %	Fiber Content Other* %	Compressionsal Resilience	Thickness at 0.002 lb/in^2 Loading Cycle mils	Thickness at 0.002 lb/in^2 Recovery Cycle mils	Total Compression .002 to 0.1 lb/in^2 Loading Cycl mils
			Group A Serges			
745	100	---	52	92	80	35
741	70	30 O	51	79	69	29
742	70	30 Da	52	81	73	29 ~~54~~
743	70	30 O	53	75	67	26
744	70	30 Da	52	76	66	28
746	70	30 V	48	88	76 - 55].	31
747	70	20 V, 10 N	46	81	71	28
748	70	30 Ch	48	76	65	28
			Group B Serges			
54047	70	30 Dy	53	64	55	25
54048	50	30 VC, 20 N	51	73	64	26
54049	50	30 A, 20 N	53	64	57	22
20	70	30 Dy	49	80	67	33
21	50	30 VC, 20 N	49	87	74	33
19	50	30 A, 20 N	47	84	71	34
			Group C Serges			
N1	---	100 N	42	67	54	24
N2	---	100 N	38	67	54	23
28	---	100 C	24	78	55	33
			Group D All Wool Serges			
A	100	---	54	77	66	31
13	100	---	53	114	98	45
H	100	---	54	86	77	29
K	100	---	50	79	69	29
			Group E Coverts			
26	100	---	51	141	126	43
22	70	20 V, 10 N	51	133	116	44
23	60	30 V, 10 N	51	113	98	41
24	50	40 V, 10 N	50	112	97	40
25	40	50 V, 10 N	51	123	107	43

* O = Orlon, Da = Dacron, Ch = Chemstrand, Dy = Dynel, N = Nylon
VC = Vicara, A = Acetate, V = Viscose, C = Cotton

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Table 3, Report 2. Compression Measurements of Wet Blended Fabrics in the Pressure Range 0.002 to 0.1 lb/in^2.

Sample No.	Fiber Content Wool %	Fiber Content Other* %	Compressional Resilience %	Thickness at 0.002 lb/in^2 Loading Cycle mils	Thickness at 0.002 lb/in^2 Recovery Cycle mils		Total Compressio .002 to 0.1 lb/in^2, Loading Cyc mils
Group A Serges							
745	100	---	33	85	69	51	33
741	70	30 O	33	72	58	81	27
742	70	30 Da	36	79	65	[illegible]	29
743	70	30 O	35	71	60		27
744	70	30 Da	34	71	56		28
746	70	30 V	31	84	65		32
747	70	20 V, 10 N	29	79	59		29
748	70	30 Ch	32	73	56		31
Group B Serges							
54047	70	30 Dy	36	62	49	[illegible]	23
54048	50	30 VC, 20 N	35	72	55		29
54049	50	30 A, 20 N	35	61	48		23
20	70	30 Dy	36	77	58		33
21	50	30 VC, 20 N	33	83	63		34
19	50	30 A, 20 N	33	76	56		32
Group C Serges							
N1	---	100 N	48	60	50	84	22
N2	---	100 N	44	61	51		19
28	---	100 C	22	59	44	75	20
Group D All Wool Serges							
A	100	---	34	66	51		26
13	100	---	30	105	77		45
H	100	---	32	83	64		32
K	100	---	36	76	58		30
Group E Coverts							
26	100	---	32	124	107	86	38
22	70	20 V, 10 N	30	117	91	78	43
23	60	30 V, 10 N	29	102	76		40
24	50	40 V, 10 N	28	106	78	73	43
25	40	50 V, 10 N	26	114	85	75	46

*See code in footnote to Table 2.

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Table 4, Report 2. Comparison of Observed Values of Thickness at Various Pressures with those Calculated from Equation (1) : $t = a + \frac{b}{p + c}$

Pressure	Wool Serge 13			Cotton Serge 28			Wool Blanket*		
lb/in^2	Obs. mils	Calc mils	Diff %	Obs. mils	Calc mils	Diff %	Obs. mils	Calc mils	Diff %
0.002	120	118	-2	85	86	+1	263	262	-0
.004	113	114	+1	79	81	+3	256	259	+1
.007	104	109	+5	72	75	+4	247	254	+3
.01	99	100	+1	67	71	+6	243	250	+3
.02	90	94	+4	59	61	+3	232	237	+2
.04	80	80	0	52	52	0	220	218	-1
.07	73	69	-5	48	46	-4	212	196	-8
.1	67	63	-6	45	43	-4	189	181	-4
.2	59	54	-8	41	39	-5	152	153	+1
.35	54	49	-9	39	38	-3	137	133	-3
.5	51	47	-8	38	37	-3	127	123	-3
.75	48	45	-6	37	36	-3	116	115	-1
1.0	46	44	-4	37	36	-3	110	110	0
1.5	44	43	-2	36	36	0	103	105	+2
2.0	42	43	-2	35	35	0	101	102	+1
Mean Difference:			4%			3%			2%

* Recovery cycle

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Table 5, Report 2. Comparison of the Constants in Equation (1) Calculated for Various Materials in the Loading Cycle (subscript 1) and in the Recovery Cycle (subscript r).

Sample No.	Material	a	c_1	c_r	b_1 at low p	b_1 at high p
13	Hairy Wool Serge	41	0.037	0.046	3.00	4.8
A	Smooth Wool Serge	34	.024	.028	1.01	2.1
28	Cotton Serge	36	.026	.031	.81	——
25	Blended Covert	49	.046	.075	3.68	6.2
CF	Cotton Flannel	23	.043	.085	1.68	3.3
HB	Wool Blankt, brushed nap	94	.085	.123	17.3	30.
RV	Rayon Velvet	53	.208	.039	0.59	1.7
SR	Sponge Rubber Mat	100	.70	.61	421.	410.
GR	Gum Rubber Sheet	34.5	.026	.026	.097	.091
J3	Blended Jersey,[a] 3 den	26	.031	.052	.96	1.8
J5	Blended Jersey 5 den	24	.042	.066	1.69	2.8
J7	Blended Jersey 7 den	33	.038	.054	2.30	3.7
Pl-R	Blended Plaid,[b] regular	24	.027	.040	.90	1.1
Pl-C	Blended Plaid crimped	24	.030	.044	.98	1.4

a) 60% wool, 40% Vicara of the denier shown.

b) 33% wool, 67% viscose, regular or crimped as shown.

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Table 6, Report 2. The Effect of Construction Variables on Longitudinal Wicking Time.

Sample	Construction Variable	Material Tested	Wicking Time seconds
a	Thread count - 31 x 22	Fabric, filling	125
b	" " - 31 x 16	" "	205
c	" " - 30 x 14	" "	275
a	Thread count - 31 x 22	Fabric, warp	285
b	" " - 31 x 16	" "	405
c	" " - 30 x 14	" "	505
b	Filling yarn No. - 2/11 worsted	Fabric, filling	205
l	" " " 2/4 "	" "	235
a	Filling yarn no. - 2/11 worsted	Fabric, filling	125
k	" " " 2/7 "	" "	240
i	Singles twist - 5.9 tpi	Yarn	5000
j	" " 15.0 tpi	"	310

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Table 7, Report 2. Comparison of Wicking Times of Alternate Fabrics, Longitudinal Test, Warp Direction.

Sample No.	Fiber Content		Wicking Time
	Wool %	Other* %	seconds
		Group A - Serges	
745	100	---	greater than 15,000
741	70	30 O	180
742	70	30 Da	870
743	70	30 O	250
744	70	30 Da	630
746	70	30 V	75
747	70	20 V, 10 N	140
748	70	30 Ch	300
		Group B - Serges	
54047	70	30 Dy	1150
54048	50	30 VC, 20 N	1610
54049	50	30 A, 20 N	85
20	70	30 Dy	1740
21	50	30 VC, 20 N	3660
19	50	30 A, 20 N	170
		Group C - Serges	
N1	---	100 N	35
N2	---	100 N	65
28	---	100 C	16
		Group D - All Wool Serges	
A	100	---	Greater than 15,000
13	100	---	Greater than 15,000
H	100	---	160
K	100	---	1710
		Group E - Coverts	
26	100	---	Greater than 10,000
22	70	20 V, 10 N	115
23	60	30 V, 10 N	17
24	50	40 V, 10 N	20
25	40	50 V, 10 N	15

* See code in footnote of Table 2.

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Table 8, Report 2. Comparison of Longitudinal and Transverse Wicking on Blended Shirtings.

Sample No.	Fiber Content		Thickness at 0.002 lb/in^2	Wicking Time	
	Wool %	Nylon %	mils	Longitudinal min	Transverse sec
2	85	15	138	10	17
4	75	25	122	80	460
1	85	15	138	100	640
12	100	0	178	95	3400
6	85	15	123	greater than 240	greater than 10,000

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Table 9, Report 2. Surface Contact as Estimated by Thermal Conductivity (Hot Penny) Method

Sample No.	Fiber Content: Wool %	Fiber Content: Other* %	Time to Cool Hot Penny 7.5° C. (t1/2) sec
A	100	---	61
13	100	---	83
745	100	---	77
741	70	30 O	70
742	70	30 Da	73
743	70	30 O	73
744	70	30 Da	66
746	70	30 V	78
747	70	20 V, 10 N	74
748	70	30 Ch	74
54047	70	30 Dy	60
54048	50	30 VC, 20 N	69
54049	50	30 A, 20 N	63
20	70	30 Dy	66
21	50	30 VC, 20 N	75
19	50	30 A, 20 N	77
28	---	100 C	46
N1	---	100 N	55
N2	---	100 N	53

* See code in footnote to Table 2.

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Table 10, Report 2. Estimated Values for Ratio of Number of Surface Fibers (n) to Mean Height of Fuzz (l) of Simulated Pile Fabrics and Estimated n for Three Serges, Calculated from Hot Penny Data.

Sample	Fabric	Ratio of Number of Surface Fibers per Unit Area to Mean Height, Calculated from Hot Penny Experiment	Observed Ratio of Number of Surface Fibers per Unit Area to Mean Height	Mean Height of Fuzz*	Number of Surface Fibers Per Unit Area
		cm^{-3}	cm^{-3}	cm	cm^{-2}
1P	Simulated Polyethylene Pile Fabric	220	220	---	---
2P	" "	450	440	---	---
3P	" "	150	130	---	---
28	Cotton Serge	6.1×10^5	---	1.4×10^{-2}	8.6×10^3
13	Hairy Wool Serge	$.56 \times 10^5$	---	3.4×10^{-2}	1.9×10^3
A	Smooth Wool Serge	1.4×10^5	---	1.4×10^{-2}	2.0×10^3

* Estimated from the thickness difference determined at 0.1 and 2.0 lb/in^2.

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Table 11, Report 2. Thermal Resistance of Alternate Fabrics.

Sample No.	Fiber Content: Wool %	Fiber Content: Other* %	At 1.0 lb/in^2: Intrinsic Thermal Resistance °C sec m^2/cal	At 1.0 lb/in^2: Specific Resistance °C sec m^2/cal inch	At 0.002 lb/in^2: Intrinsic Thermal Resistance °C sec m^2/cal	At 0.002 lb/in^2: Specific Resistance °C sec m^2/cal inch
			Group A - Serges			
745	100	---	0.077	1.90	0.197	2.14
741	70	30 O	.066	1.77	.152	1.92
742	70	30 Da	.069	1.77	.162	2.00
743	70	30 O	.064	1.85	.157	2.09
744	70	30 Da	.058	1.69	.148	1.95
746	70	30 V	.070	1.66	.167	1.90
747	70	20 V, 10 N	.064	1.62	.171	2.11
748	70	30 Ch	.054	1.59	.155	2.04
			Group B - Serges			
54047	70	30 Dy	.054	1.68	.135	2.11
54048	50	30 VC, 20N	.062	1.74	.158	2.16
54049	50	30 A, 20 N	.056	1.69	.132	2.06
20	70	30 Dy	.064	1.80	.168	2.10
21	50	30 VC, 20 N	.068	1.77	.173	1.99
19	50	30 A, 20 N	.068	1.88	.178	2.12
			Group C- Serges			
N1	---	100 N	.046	1.35	.133	1.99
N2	---	100 N	.052	1.42	.131	1.96
28	---	100 C	.039	1.07	.154	1.97
			Group D - All Wool Serges			
A	100	---	.062	1.73	.147	1.91
13	100	---	.088	1.88	.215	1.89
H	100	---	.074	1.75	.156	1.81
K	100	---	.066	1.78	.150	1.90
			Group E - Coverts			
26	100	---	.123	1.84	.260	1.84
22	70	20V, 10 N	.109	1.84	.246	1.85
23	60	30 V, 10 N	.083	1.66	.220	1.95
24	50	40 V, 10N	.088	1.74	.216	1.93
25	40	50 V, 10N	.093	1.70	.257	2.09

* See code in footnote to Table 2.

Figure 1, Report 2. The Thickness-Pressure Relationship for a Fabric: $t = a + \frac{b}{p+c}$

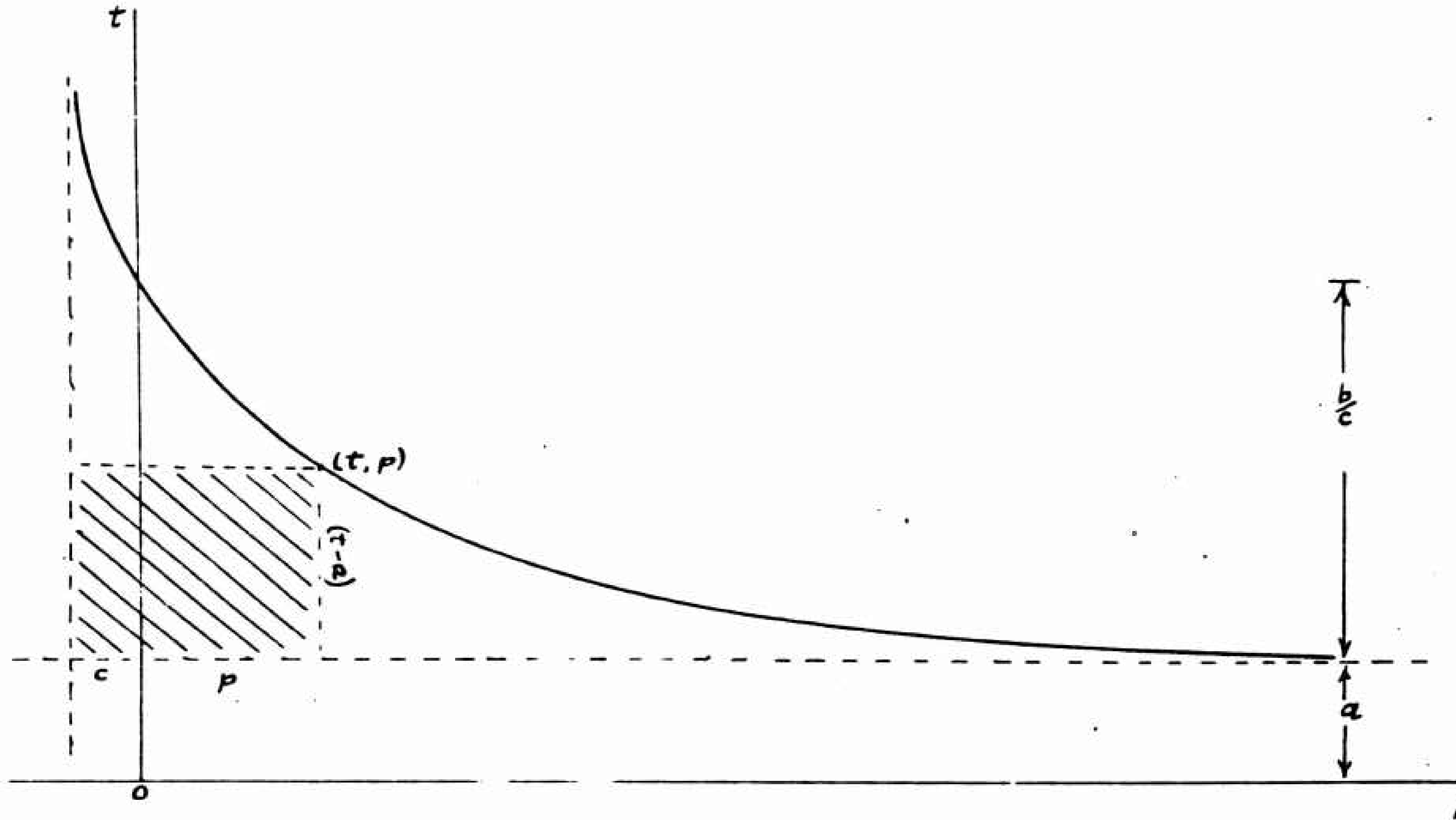
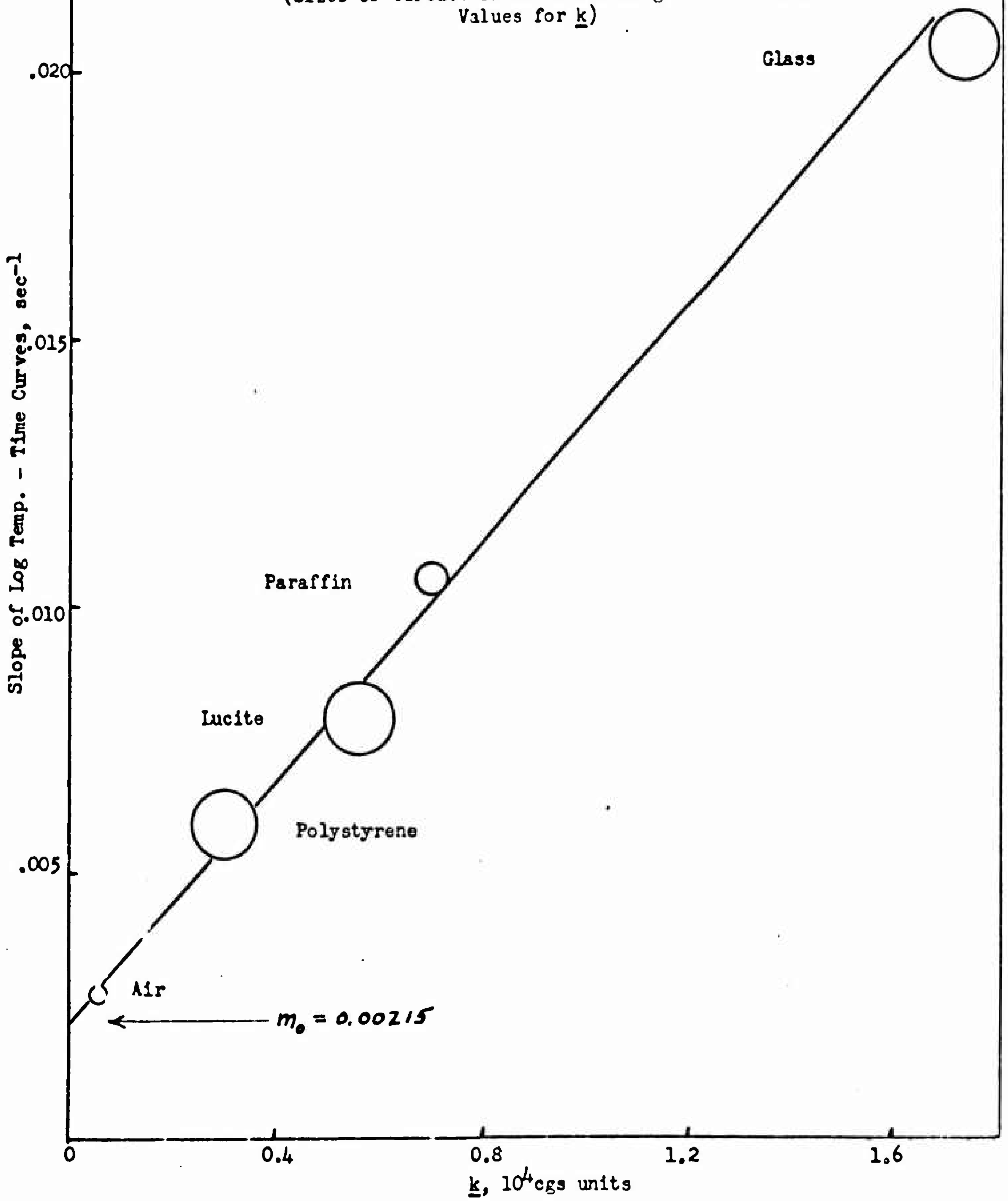
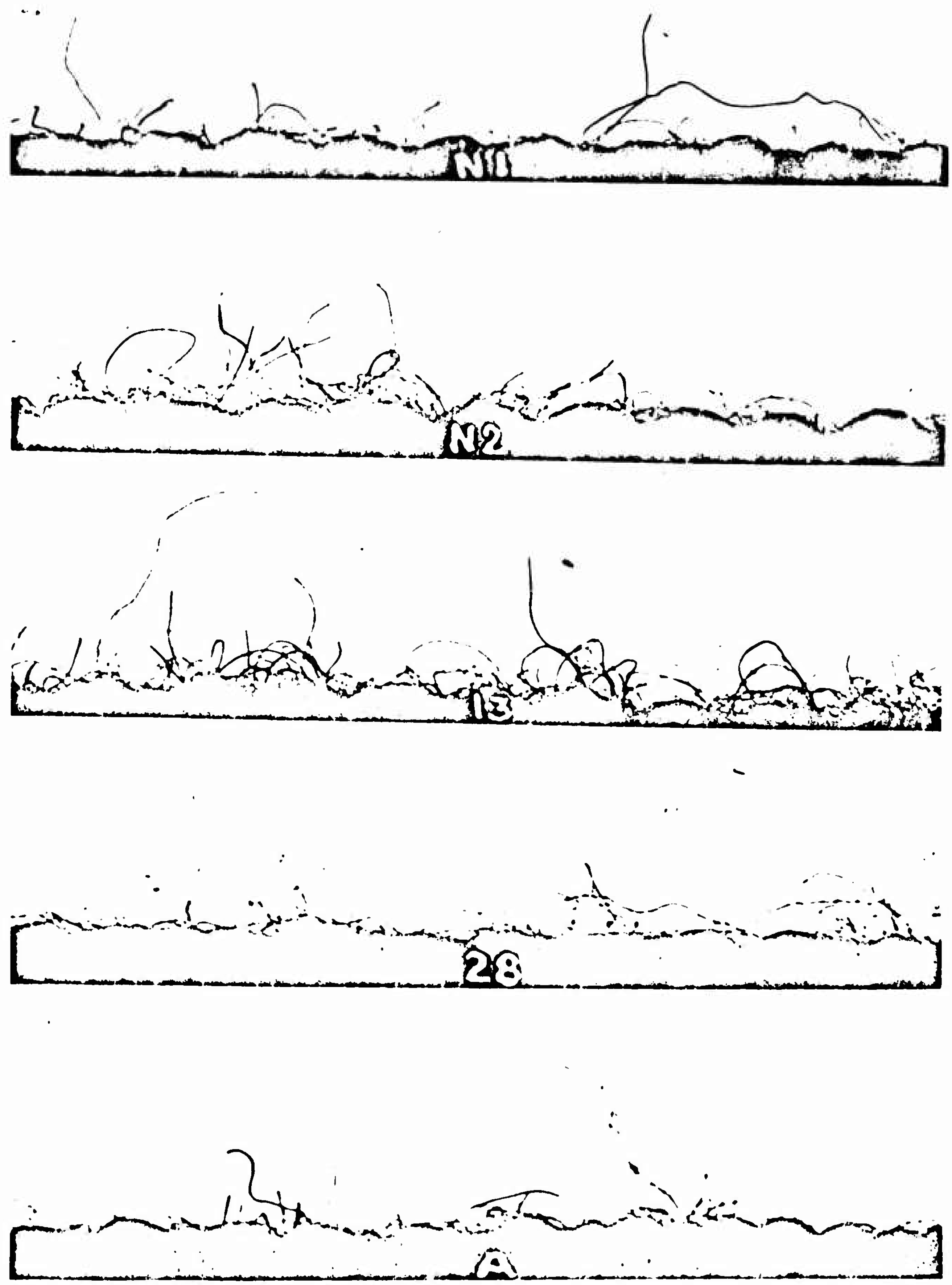


Figure 2, Report 2. The Relationship Between m, the Slope of the Log Temperature Change - Time Curve in a "Hot Penny" Experiment and k, the Thermal Conductance.

(Sizes of Circles Indicate the Range of Literature Values for k)




N1
N2
13
28
A